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13. ABSTRACT

Several materials are purported to be fast setting and capable of supporting loads in a relatively short time after casting. These materials are generally mixtures of several components. Some of the materials require only the addition of water prior to mixing, while some are admixtures or accelerators that are added in varying amounts to a specified cement at the time of mixing. Literature pertaining to fast setting materials was surveyed. Copies of all available pertinent information were arranged in eight annexes. The information was classified as follows: calcium sulfates; high alumina cements; very fine cements; silico-phosphate cements; accelerators, organic; accelerators, inorganic; miscellaneous; and general. The contents of each annex are summarized herein. A list of the literature examined is also included.

MISCELLANEOUS PAPER C-73-1

FAST SETTING CEMENT LITERATURE SURVEY

by

C. F. Derrington

January 1973

Conducted by U. S. Army Engineer Waterways Experiment Station
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Foreword

The literature survey included herein was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) for The Dow Chemical Company, Product Department Laboratories, Midland, Michigan, at the request of Mr. G. M. Hart in letter of 13 May 1970, subject: Literature Survey Re Air Mobility Fast Setting Cement - Contract No. DACA-39-70-C-0022. WES personnel had previously discussed the survey with Dow representatives Messrs. R. D. Eash and G. F. Allen during their visit to WES on 5 May 1970.

Ms. Clara F. Derrington, Research Chemist, Concrete Laboratory, WES, made the survey, which is limited to a review of literature pertaining to materials. Information concerning structural requirements can probably best be obtained from other sources. The survey was made under the general supervision of Mr. Bryant Mather, Chief, Concrete Laboratory, and Director, Concrete Technology Information Analysis Center (CTIAC).

This survey is CTIAC Report 1. The cost of reproduction of it was defrayed by TISA Project 02/07.

Director of WES during preparation and publication of this survey was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

Contents

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Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
square yards	0.836127	square meters
gallons (U. S.)	3.785412	cubic decimeters
pounds	0.45359237	kilograms
pounds per square inch	0.00689476	megapascal (= MN/m^2)
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

Summary

Several materials are purported to be fast setting and capable of supporting loads in a relatively short time after casting. These materials are generally mixtures of several components. Some of the materials require only the addition of water prior to mixing, while sc are admixtures or accelerators that are added in varying amounts to a specified cement at the time of mixing.

Literature pertaining to fast setting materials was surveyed. Copies of all available pertinent information were arranged in eight annexes. The information was classified as follows: calcium sulfates; high alumina cements; very fine cements; silico-phosphate cements; accelerators, organic; accelerators, inorganic; miscellaneous; and general. The contents of each annex are summarized herein. A list of the literature examined is also included.

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FAST SETTING CEMENT

Literature Survey

Introduction

1. There are several materials that are purported to be fast setting and capable of supporting loads in a relatively short time after casting. These materials are generally mixtures of several components. Some of the materials require only the addition of water prior to mixing, while some are admixtures or accelerators that are added in varying amounts to a specified cement at the time of mixing.

2. Copies of all available pertinent information were arranged in Annexes A through H as shown below. Copies of the entire reports were included in some instances, abstracts in others. The literature examined is listed at the end of this report. The information examined is classified as follows:

Annex	Type Material	Annex	Type Material
A	Calcium sulfates	E	Accelerators - organic
B	High alumina cements	F	Accelerators - inorganic
C	Very fine cements	G	Miscellaneous
D	Silico-phosphate cements	H	General information

The contents of each annex are summarized in the following paragraphs.

Summary

3. Annex A - Calcium sulfate type materials.

a. Fast-Fix. The Western Co. has developed materials designated as Fast-Fix with rapid setting and high strength properties. Published data show that mortars made with Fast-Fix have flexural strengths of 546 psi* and compressive strengths of 2318 psi at 30 min, while concrete made with Fast-Fix has flexural strengths of 400 psi and compressive strengths of 1800 psi.

There are several Fast-Fix materials with various designations as Fast-Fix 1, Fast-Fix 2, etc. The name Fast-Fix denotes a combination of hemihydrate alpha type gypsum, Portland cement, and a dispersing agent. The Portland cement varies from 5 to 20 percent in these materials.

Nosseir and Griffin investigated mix designs for Fast-Fix 1 and Fast-Fix C-1 concrete, and the results are found in TR 613 and TR 651. Fast-Fix C-1 cement contained 20 percent Portland cement, while Fast-Fix 1 contained only 5 percent Portland cement. Fast-Fix 1 concrete apparently showed maximum strength at 1 hour, while Fast-Fix C-1 concrete continued to gain strength with age. The data indicate that for concretes with an age of 1 hour, compressive strengths up to 3300 psi can be achieved with proper selection of constituents. Decreasing the water-cement ratio increases the compressive strength and decreases the setting time, but generally the Fast-Fix C-1 cement concrete requires longer setting time than Fast-Fix 1. Fast-Fix C-1 concrete is more resistant to erosion by flowing water than Fast-Fix 1 concrete. Air-dried Fast-Fix C-1 cement concrete gains more strength at age of 28 days than when fog-cured.

In another investigation, Setser et al (Vol I: "Rapid Repair of Bomb-Damaged Runways") selected and evaluated several resin formulations and 250 fast-setting cement formulations in an effort to find the most promising materials that could meet the following specification: (1) support a 29,000-lb rolling wheel load within 30 min after placement in a

* A table of factors for converting British units of measurement to metric units is presented on page ix.

bomb-crater repair area, within an ambient temperature range of -5 to +110 F, (2) adapt to rapid and continuous mixing and placement and (3) be self-leveling. Four materials manufactured by U. S. Gypsum that proved most adaptable to rapid-repair techniques are, in increasing order of strength and cost:

(1) IP Cement (Fast-Fix 2)

(2) Hydrocal White (Fast-Fix 3)

(3) Ultracal 30

(4) Hydrostone (Fast-Fix 1)

Fast-Fix 1 consisting of 95 percent Hydrostone, 5 percent Portland cement, and 0.5 percent TF-4 was chosen over all the other materials because of its high strength, hard wearing surface, and general slurry characteristics such as set time, viscosity, and adaptability to fillers. This formulation provides a 30-min compressive strength of 3500 psi and flexural strength of 600 psi. Among other materials tested that did not meet the requirements were Portland cement, Lumnite cement, Por-rock, Mirament, Speed Crete, Floc-roc, Sika accelerators, Darex, Dehydratine 80, and sodium silicate.

Based on the findings reported in Vol I above, Pruitt et al. in Vol II, "Rapid Repair of Bomb-Damaged Runways," describes additional physical properties of Fast-Fix 1, 2, and 3. Each contains 95:5 weight ratios of $CaSO_4 \cdot \frac{1}{2}H_2O$ and Portland cement, plus 0.5 percent TF-4. The only differences in the cements are in the processing procedures used on the hemihydrate. The report covers the design, fabrication, and testing of equipment to disperse Fast-Fix at rates up to 1000 gpm, and the demonstration of the overall material-equipment procedure performed at Eglin Air Force Base. The demonstration showed the excellent capability for rapid repair of a bomb crater, but there was an apparent need for improved equipment in order to accomplish the repair more efficiently.

b. U. S. Gypsum Co. materials. Hydrostone, Hydrocal, and Ultracal are recommended for high early strength. Data sheets from U. S. Gypsum show Hydrostone to have an 11,000-psi compressive strength in the dry state and to set up in 20 to 25 min.

Compressive strengths of grout mixtures containing Hydrostone, cement, and water and made at the Concrete Division varied from 600 to 1400 psi at 16 hours, depending upon the mix. The highest compressive strengths obtained using Type III cement and Plaster of Paris (hemihydrate) was 1742 psi at 1 day. A strength of 6775 psi was found for a mixture of Hydrostone and water at 24 hours when cured at 100 F. Strength tests were not determined at earlier ages.

c. Others. Laboratory tests showed that a grouting mixture containing F-181-R DAKORAN allowed a working time of 10 min with compressive strengths at 30 min and 1 hour of 1810 and 3250, respectively.

It is evident by the data inclosed that the addition of $CaSO_4$ type materials does produce early set times and high strengths. It is reported, also, that the addition of 1.5 percent $CaCl_2$ to clinkers containing more than normal amounts of hemihydrate increases the early strengths.

4. Annex B - High alumina cements.

a. High alumina cements have been proposed and successfully used as quick setting early strength materials. Experience and investigations have shown that high alumina cements perform particularly well where the ambient temperatures do not exceed 25 C. When high alumina cement mortar or concrete is exposed to warm, moist conditions, there is a significant reduction in strength. The cause of the loss of strength is attributed to the conversion of hexagonal aluminates to the more chemically stable cubical aluminates. The water-cement ratio of the mix greatly influences this conversion.

b. Taylor reports that the setting times of high alumina cements are from 5 to 30 min and that useful strengths may be obtained after 15 to 60 min. The setting time is maximum at 30 C. Above 30 C the setting time is reduced as the temperature rises. High alumina cements are resistant to acid solutions with a minimum pH of 4.0, waters containing CO_2, and sulphate solutions.

c. Booth and Whitehurst claim that the compressive strengths of aluminous slag cements may be improved by a factor of 2 to 15 by the addition of 2.5-4.0 percent fluoride and other additives such as sugar, sodium metaphosphate, etc.

d. Abstracts of work done in Russia indicate that changes in compressive strength of alumina cements with curing depend upon kinetics of phase transformations and are dependent upon temperature and hardening conditions. Higher initial strengths were also reported for aluminum cements containing a greater than normal percentage of SO_3.

e. Wilson and Wood (France) report that setting time of alumina cements obtained from phosphorus furnace slags may be increased by treating the cement with CO_2.

f. Robson investigated mixtures of Portland cement and high alumina cements and noted that setting time of the mixtures is affected by the method in which both cements are mixed. Addition of Portland cement to the alumina cement causes initial stiffening but relatively slow final setting and hardening; addition of alumina cement to Portland causes quick set. Mortars made using 100 percent Lumnite cement showed compressive strengths of 6380 psi at 1 day. High temperature curing produces lower strengths of high alumina cements.

g. Approximately 2000 sq yd of concrete were replaced at aircraft runways at Yokota Air Base, Japan. Requirements for the job were that the mixtures used for repairs should have an average flexural strength of 700 psi at 5 to 6 hours age and that 12 hours was the maximum period of disruption that could be allowed. Asphaltic concrete was first attempted but was unsuccessful. Successful repairs were made that met the job criteria by the use of an aluminous cement produced by Asahi Glass Co., Ltd. It was recommended as a result of this job that, for future jobs, pouring should be confined to the colder months, that direct sunlight should be avoided, and that 300 sq yd should be the maximum area which can be replaced satisfactorily by a single paving machine.

h. Lancaster describes the thin patching of 22 spalled areas of a road at Longton, Lancashire. The repairs were made with various mortar mixes. Those mixes showing the fastest setting times were mixtures of 80 percent high alumina and 20 percent Portland cement. These mixtures performed well when trafficked four or five hours after laying, but it was noted that the properties of high alumina Portland cements may vary with different batches of cement. No strength data were available in this report

4. Unpublished laboratory test data obtained by the Concrete Division show average 1 day compressive strengths of mortar cubes made with Ciment Fondu to be approximately 7400 psi when stored at 73°F, 7100 psi at 60°F, and 6300 psi at 100°F. A grouting mixture of Ciment Fondu and water evinced compressive strengths of approximately 7000 psi at 18 hours, while a grout mixture containing Lumnite cement, limestone sand, water, and plastiment showed a compressive strength of approximately 6700 psi at 1 day.

5. Annex C - Very fine cements.

a. The fineness of Portland cement is a significant factor affecting the rate of hardening and early strength development. Brunauer et al showed that (1) clinker can be ground to desired fineness by using a variety of grinding aids, (2) proper kinds of surface-active additives can provide excellent workability, and (3) much greater strengths than normal of hardened Portland cement pastes can be obtained. Data in the report show that by increasing the fineness to a specific surface of approximately 8000 cm^2/g and by using the proper grinding aid and lignosulfonate, compressive strengths of 11,000 to 14,000 psi could be obtained at 1 day. Type I cement gives earlier strength development than Type II. Compressive strength of 3000 psi at 9 hours was obtained for a Type I cement, with 0.5 percent TMN as grinding aid and additional K_2CO_3 and lignosulfonate.

b. Bennett and Collings investigated high early strength concrete using a very fine Portland cement. A special cement with a specific surface of 7420 cm^2/g was compared with a Portland cement of 2770 cm^2/g, a rapid hardening Portland cement of 4900 cm^2/g, the same rapid hardening cement plus 2 percent $CaCl_2$, and a high alumina cement of 3610 cm^2/g. Most tests involved an agg-cement ratio of 3:1, so that low water-cement ratios could be used. Compressive strengths at 8 hours of 4-in. cubes were highest (9650 psi) for the high alumina cement and next highest (3350 psi) for the very fine Portland cement. Strengths at less than 8 hours were not reported.

c. Abstracts from foreign journals also indicate that particle size distribution and very fine cements will cause an early gain in strength of cement mortars and concrete. The high initial strength is assisted by the 0-3μ fraction.

d. Although none of the values reported in the articles above showed strength data at 1 hour, it is evident that the compressive strength would be less than 3000 psi. However, the data do suggest that very fine Portland cement with additional admixtures or accelerators such as $CaCl_2$, $CaSO_4$, etc., may be altered to produce even higher strengths at 1 to 2 hours

6. Annex D - Silico-Phosphate cements.

a. Wells in 1968 reported on a limited investigation of inorganic materials that would set at low temperature and which would have compressive strengths of about 10,000 psi. The cement with the greatest potential was a silicate cement composed of alumina powder, silica powder, phosphoric acid, and water. No early (<1d) strengths were reported, but compressive strengths at 1 week and 1 month showed about a 50 percent improvement over Portland cement products. It was concluded from this study that the pursuit of the silicate cement should be halted due primarily to the excessive costs for large quantities.

plus 2 percent $CaCl_2$, and a high alumina cement of 3610 cm^2/g. Most tests involved an agg-cement ratio of 3:1, so that low water-cement ratios could be used. Compressive strengths at 8 hours of 4-in. cubes were highest (9650 psi) for the high alumina cement and next highest (3350 psi) for the very fine Portland cement. Strengths at less than 8 hours were not reported.

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b. Mortar cubes using Sigunit and Na_2CO_3 were made in the laboratory of the Concrete Division. The cubes set up in a few minutes but no early strengths were obtained.

c. Increased early strength of concrete can be obtained with the addition of $CaCl_2$. An addition of 2 percent $CaCl_2$ to a Type III cement requires approximately 14 hours to attain strengths of 2000 psi.

d. A combination of KOH and $CaCl_2$ is purported, also, to improve initial strength.

9. Annex G - Miscellaneous.

a. The Portland Cement Association reports in a brochure that Regulated-Set is a modified Portland cement that can be made to set up from 1 to 30 min. Mortars (1:2) and C-109 mortars are purported to show about 1950- and 950-psi compressive strengths at 1 hour, respectively.

b. Huron Cement Co., in an information bulletin dated December 1969, stated that Set Regulated cement was in the development stage, but suggested mixes of 88 percent special clinker, 10 percent anhydrous calcium sulfate, and 2 percent hemihydrate calcium sulfate for early set and high strength material. Mortars made at the Concrete Division with varying amounts of these additives and varying amounts of water showed compressive strengths at 1 hour of 250 to 920 psi.

c. Darcrete is a fast-setting cement that is purported to take an initial set in 10 to 15 min and to have a minimum compressive strength of 2200 psi in 24 hours.

d. Mari-crete is a commerical product that claims high strength and may be used for patching and repairing. Compressive strengths at 24 hou are about 3000 psi, and tensile strengths vary from approximately 150 to 350 psi, depending upon the curing conditions.

e. Quick-Wotaito is a liquid accelerator for cement that sets up from 30 sec to 1 hour. The available data sheets do not state the strength of mixes made with Quick-Wotaito.

f. There are other means that may produce high strength concrete. They include addition of iron as aggregate, physical treatment of clinker, addition of highly reactive SiO_2 or CaO, and mixtures of iron powder and aqueous solution of dichromate or permanganate and a chloride.

g. A project plan entitled "Cementitious Materials for Ship Salvage," is included in this Annex. The project involves an investigation of high early strength Portland cement pastes made with seawater and various admixtures. The results of the investigation may prove helpful in the search for a fast-setting cement.

10. Annex H - General information. A bibliography and several articles or abstracts on high strength concretes are included in this Annex. These articles do not pertain necessarily to high early strength concrete, but the information in the articles and the discussion of factors that contribute to high strength concrete should be beneficial in consideration of the development of a quick set high early strength material. Some of the factors, in addition to the ones presented in the other Annexes, that should be considered or investigated to obtain high early strength are as follows: compression, high frequency vibration, improvement of bond by use of cementitious aggregates, low water-cement ratios, curing conditions, improved grading of particle sizes, type of mixing, and sequence of addition

of materials during mixing. A combination of factors such as the addition of accelerators and/or admixtures (as discussed in this report) to improved Portland cement (fineness, special clinkers, etc.) plus improved methods of mixing and compaction should result in a concrete having quick set properties and high strengths.

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NOTE: Letters in parentheses indicate Annex in which reference is found.

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